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(54) Method and apparatus for assembling camshafts.

(57) Camshaft assemblies, methods and apparatus are provided for making camshafts (10) by the expansion of tubular shafts (11) into pre-located cams (12), journals (14) and other elements, if desired. Features of the camshafts (10) include tri-lobe or poly-lobe element openings (15), preferably splined or serrated for low-energy filling and high torque-capacity, and high-strength low-alloy mild steel tubular shaft material. The method emphasizes loading the shaft (11) to prevent axial lengthening thereof during expansion thereof by a technique such as mechanical "ballizing". The apparatus (27) includes adjustable thrust blocks (38) and locating plungers (39) with incorporated flush pin gauges (40,42) together with hydraulic or other loading means (51), all for use in carrying out the assembly method with various benefits from the incorporated features.

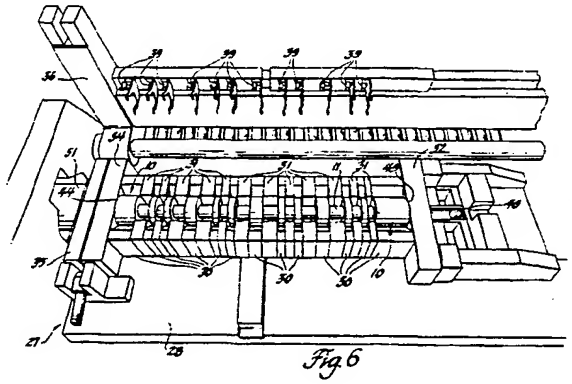

Fig.6

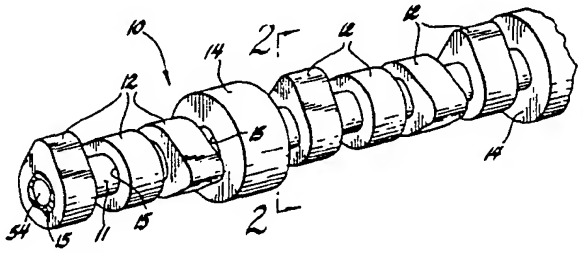

Fig.1

EP 0 389 070 A2

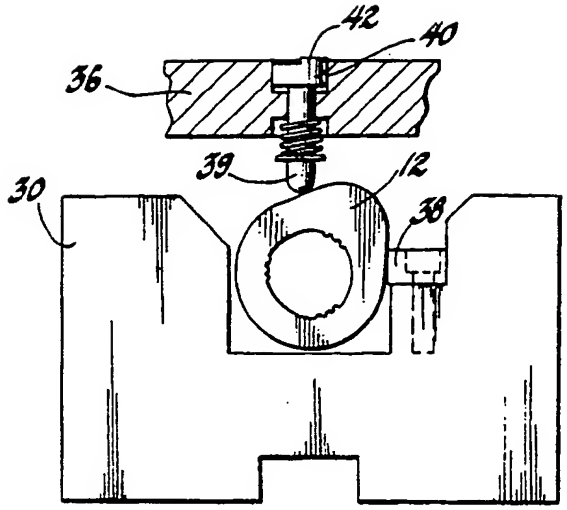

Fig. 9

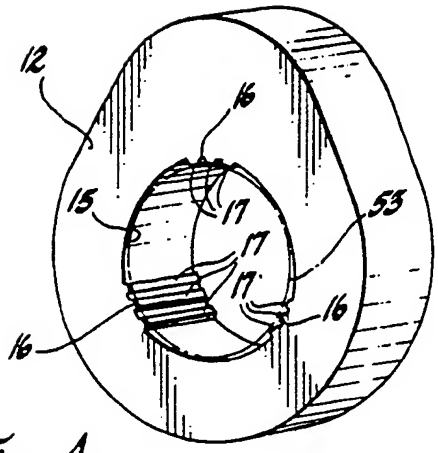

Fig. 4

METHOD AND APPARATUS FOR ASSEMBLING CAMSHAFTS

This application is divided out from European patent application No.88301147.0, filed 11 February 1988.

Technical Field

This invention relates to camshafts for internal combustion engines and similar engines. In particular, the invention relates to methods and apparatus for the manufacture of camshaft assemblies.

Background

United States patent 4,597,365 discloses a camshaft assembly and method involving retention of cam and journal elements on a hollow shaft by expansion of the shaft into engagment with preshaped openings of the elements. Various other camshaft assemblies and methods are also shown by the prior art. While certain of these arrangements provide benefits in economy and structure, further economies are desirable for making the most efficient use of this technology.

Summary of the Invention

The present invention provides improved camshaft assembly, manufacturing procedures and equipment which yield benefits in both structural soundness and economy of manufacture for assembled camshafts, particularly of the type described in the afore-mentioned U.S. patent 4,597,365, the disclosure of which is incorporated herein by reference.

The manufacture of an improved camshaft assembly by a method according to the invention includes the use of non-round element openings comprising so-called curved polygons of preferably uniform diameter and having odd numbers of slightly eccentric lobes. These configurations minimize the energy required for their filling by expansion of an associated hollow shaft whilst providing a joint of high torque capacity. The addition of one or more small grooves or splines on the ends of the lobes further improves the torque capacity. By use of preferred materials for the shaft, the torsional strength relative to the expansion energy required may be further improved.

In the manufacturing process, control of the length and straightness of the assembly and the ease of its removal from the assembly fixture are aided by the added step of loading the hollow shaft from the initially expanded (front) end during the mechanical expansion procedure so as to prevent the assembly lengthening and locking itself in the fixture.

In the assembly apparatus, the use of adjustable locator blocks and spring-loaded guide pin plungers assists in accurately locating the cam elements in their proper angular positions on the shaft prior to their being locked in position by shaft expansion. In addition, the guide pins may have stepped heads co-operating with external gauging surfaces of the fixture to permit visual or mechanical indication of proper or improper positioning of the cams and their presence in the fixture during assembly.

These and other features and advantages of the invention will be more fully understood from the following description of certain embodiments of the invention taken together with the accompanying drawings.

Brief Drawing Description

In the drawings:

Figure 1 is a pictorial view of a portion of an internal combustion engine camshaft assembly formed in accordance with the invention;

Figure 2 is a transverse cross-sectional view of a portion of the camshaft assembly from the plane indicated by the line 2-2 of Figure 1;

Figure 3 is a longitudinal cross-sectional view of a portion of the camshaft assembly from the plane indicated by the line 3-3 of Figure 2;

Figure 4 is a pictorial view of a separate cam element prior to assembly and having a tri-lobe opening according to the invention with inwardly-splined lobes;

Figure 5 is a graphical presentation of the development of a tri-lobe configuration having uniform diameters according to the invention;

Figure 6 is a pictorial view showing a novel assembly apparatus and fixture for assembling camshafts according to the invention;

Figure 7 is a diagramatic pictorial view of portions of the novel apparatus for mechanically loading the shaft during the course of camshaft assembly by a process in accordance with the invention;

Figure 8 is a pictorial view similar to a portion of Figure 6 and showing an alternative apparatus for hydraulically loading the shaft;

Figure 9 is a transverse cross-sectional view of a portion of Figure 6; and

Figures 10a-10e are fragmentary cross-sec-

tional views illustrating various positions of flush pin gauges used in the apparatus of Figure 6.

Detailed Description

Referring now to the drawings in detail, numeral 10 generally indicates part of a finished camshaft assembly formed in accordance with the invention. Camshaft 10 includes a hollow supporting tubular shaft 11 which has been expanded in a manner to be subsequently described.

While the shaft may be made of ordinary low carbon steel as noted in US-A-4,597,365, it is preferable to make the shaft 11 of a mild steel of High Strength Low Alloy specification such as SAE 1022 HSLA. The steel tubing used to make the shaft may be of a type which is electric resistance-welded and drawn over a mandrel, having a yield strength of 310264.2 -379211.8 kPa (45,000 - 55,000 psi).

Fixedly positioned on the tube 11 are a plurality of cam elements 12 and journal elements 14. Additional elements such as gears, eccentrics or sprockets could also be included if desired. The elements 12, 14 are longitudinally spaced and the cam elements 12 are angularly oriented in predetermined positions for actuating valve gear in an internal combustion engine. The cam elements 12 are preferably forged and hardened, either fully or on the wearing surfaces thereof, and the journal elements 14 may be similarly formed or, if desired and their operation permits, may be formed of non-hardened material.

The forged, or otherwise formed, cam and journal elements are provided with shaft-receiving openings 15, which are preferably non-circular to positively lock the elements onto the shaft when it is expanded into the openings. It has been found that a preferred shape or configuration for the openings is that of a so-called curved polygon of preferably uniform, or essentially uniform, diameter. Such curved polygons may be made with any odd number of lobes, however it is preferable to obtain good results using a configuration, which is termed a tri-lobe, having three eccentric lobes 16 (see Figure 2).

Minimal eccentricity of the opening is required and preferred for achieving high torque capacity with a minimum of expansion energy exerted on deforming the shaft. An eccentricity of only 0.000127m (five thousandths of an inch) (0.000127m difference in radial height between the lobes and adjacent valleys) gives good results although greater eccentricities can be used if desired. preferably the periphery of said openings 15 has an eccentricity of from 0.4 to 1.5 percent of the uniform diameter of the openings.

To further increase the torque capacity, the addition of one or more small serrations or splines 17, preferably at the ends of the lobes, is also desirable. The addition of nine inwardly-protruding and longitudinally-extending splines 17 has been found effective. These splines are preferably arranged in closely spaced groups of three at the end of each of the lobes 16 of the openings 15. The splines protrude inwardly only about 0.000127m (0.005 inches), or approximately equal to the preferred tri-lobe eccentricity. The addition of these splines was found to increase the breakaway torque for the shaft-mounted tri-lobe elements by about 20-25 percent.

Figure 4 illustrates a cam element 12 prior to assembly and having the preferred nine-splined tri-lobe opening previously described. Obviously, in this and the previous views, the eccentricity of the opening is grossly exaggerated for clarity of illustration as it would be almost unnoticeable if drawn in its true configuration.

In Figure 5, a graphical illustration of the development of a tri-lobe figure is presented having an eccentricity 18 measured from a circle 19 defining the minimum radius of the tri-lobe perimeter 20. The developed perimeter 20 is made up of blended tangent swing radii in the form of a series of alternating long arcs 22 and short arcs 23 which are drawn from three equally spaced centres 24 spaced about the true centre 25 of the figure. The result is that the perimeter has an overall uniform height or width 26 in any direction. For simplicity, this is generally referred to as a uniform diameter 26 although it should be understood that this uniform diameter dimension passes sequentially through each of the three centres 24 and only passes through the true centre 25 when the diameter is at the midpoints of two opposing long and short arcs 22, 23.

Assembly Apparatus

Referring now to Figures 6-10 there are shown various construction features of a fixture generally indicated by numeral 27 and particularly adapted for the manufacture of camshafts according to the invention. Fixture 27 includes a base 28 on which are fixedly mounted a series of alternately disposed locators 30 and spacers 31 longitudinally aligned and sandwiched between a rear stop block 32 and a movable front back-up block 34 adjacent to a fixed front carrier block 35. A movable cover 36 is also provided.

The spacers 31 separate the journals 14, cams 12 and other elements, if any, to maintain their proper axial locations on the shaft 11. The locators 30 support the elements with their openings 15 in

alignment with one another and the lobes of the cam elements in their proper angularly-indexed positions. precision-ground locator blocks 38 may be provided on each of the cam locators to angularly position their respective cams within any desired tolerances. The blocks 38 may be individually ground or shimmed for adjustment to obtain the desired accuracy. Other means, such as wedges or screws, might be substituted for, or used together with, the locator blocks 38 if desired.

To ensure that each cam lobe is firmly held in its locator against its locator block 38, suitable positioning devices may be provided, such as the spring-biased guide pin plungers 39 best shown in Figure 9. The plungers 39 may be mounted in the cover 36 as shown or, if needed, may be positioned along a side or the bottom in the locators to properly position their respective cams. The plungers 39 are provided with heads 40 having stepped ends 42 that co-operate with the adjacent outer surfaces of the cover or other member to act as flush pin gauges. These gauges may be inspected visually or by touch or may be contacted by probes at an inspection station, such as when used in a travelling fixture pallet in high volume manufacture.

Figures 10a-10e illustrate various positions of the flush pin gauges and their indications, such as:

Figure 10a shows a gauge positioned too high, indicating the presence of an element that is too large or a cam lobe not properly positioned against its locator;

Figure 10b shows the lower step flush, indicating a cam or other element at the upper tolerance limit;

Figure 10c shows the gauge centred, indicating an element in the mid-tolerance range;

Figure 10d shows the upper step flush, indicating an element at the low tolerance limit; and

Figure 10e shows a gauge position too low, indicating a too small or missing element.

Figures 7 and 8 show in further detail certain features of the assembly apparatus including alternative means for end-loading the shaft during assembly.

Figure 7 shows a rear end 43 of the shaft and the associated rear journal 14 lying against the rear stop block 32. Similarly, a front end 44 of the shaft and the associated front journal 14 are engaged by a hardened back-up bushing 46 carried by the back-up block 34. A hollow screw actuator 47, threaded into the carrier block 35, comprises mechanically-actuated means for exerting force through the back-up bushing on the front end 44 of the shaft 11 to load the shaft during assembly. Also shown are a ball 48 and cupped rod 50 actuated by suitable means, not shown, to force the ball through the shaft during assembly.

Figure 8 illustrates a fixture whereby the front end 44 of the shaft 11 is similarly loaded through a back-up bushing 46 carried by a back-up block 34. However, the shaft-loading means comprises a hydraulic cylinder 51 threaded into the carrier block 35 and having a hydraulically-actuated hollow piston 52 that engages the back-up bushing to apply the loading force to the shaft 11.

Assembly Method

The manufacture of a camshaft assembly in accordance with the invention is in many ways similar to that described in US-A-4,597,365, although including significant differences in the following preferred steps:

1) The elements, such as cams and journals, a gear, eccentric or sprocket, are made with, or provided with, the pre-formed shaft openings 15 and are formed to relatively close, but normally unfinished, dimensions. In accordance with the invention, the openings are preferably non-round curved polygons of minimal eccentricity, preferably tri-lobes having one or more inwardly-projecting splines 17 at the lobe ends. Additionally, grooves or serrations extending outwardly from or into the tri-lobe surface, or other variations, may be used. The tri-lobe or other odd-lobed curved polygon shape requires lower energy for filling by tube expansion while giving high breakaway torques for the completed assembly. Displacement of material from the valleys into the adjacent lobes with a minimum of expansion due to the preferred constant diameter, or height, of the polygon eccentric perimeter is believed to be an advantage of this configuration that leads to the lower energy requirement.

2) A tubular shaft 11 is provided, preferably made of high-strength low-alloy mild steel such as SAE 1022 HSLA. The tubular shaft may be of the resistance-welded type, sized by drawing over a mandrel and having a yield strength of 310264.2 - 379211.8 kPa (45,000 - 55,000 psi). This low yield strength combines with significant work-hardening after yielding to provide low expansion energy with significantly higher breakaway torques after assembly than other materials. The shaft outer diameter is circular and sized to fit closely but freely within the eccentric shaft openings 15 of the elements 12 and 14. The dashed line 53 in Figures 2 and 4 represents the shaft outer diameter before expansion. Camshafts have been made with shafts of 19.1 mm, 22.22 mm and 25.4 mm (3/4, 7/8 and 1 inch) outer diameters but other sizes including larger and smaller diameters could be utilized if desired.

3) The cam, journal and other elements, if

any, are positioned in a fixture such as fixture 27 with their openings 15 aligned on a common axis. The fixture may be similar to, but preferably differs from, that described in US-A-4,597,365 in various ways, including the construction of the locators and spacers and the addition of the locating and gauging means and the shaft end-loading means previously described.

4) The fixture is closed, holding the elements in position and the shaft is inserted into the openings 15 in a predetermined longitudinal position. The shaft ends are then loaded by hydraulic, mechanical or other force-applying means with a force sufficient to prevent substantial longitudinal growth of the shaft during the subsequent steps.

5) The shaft is expanded in any suitable manner. Mechanical expansion by a ball 48 forced through the tubular shaft 11 from one end, called the front end 44, to the other, called the rear end 43, is the preferred process. With this process, sometimes known as "ballizing", a uniformly-sized smooth interior 54 is formed within the tubular shaft.

The ball is preferably large enough to expand the tubular shaft into full engagement with the element openings 15 and radially beyond the openings between the elements, as is shown clearly in Figure 3, so that the elements are permanently fixed in their established positions, both angularly and longitudinally. Preferably the ball has an outer diameter which is greater than the initial diameter of the tubular shaft by an amount greater than the sum of (1) the eccentricity of the cam element opening and (2) the initial diametral clearance between the tubular shaft, prior to the expansion thereof, and the least radial dimension of the cam element opening, but which is less than three times that sum. In an embodiment wherein the initial clearance between the tri-lobe openings 15 and the shaft 11 before expansion was 0.000203 m (0.008 inches) on the diameter and the tri-lobe eccentricity was the preferred 0.000127 m (0.005 inches), the use of a ball 48, oversize by 0.000889 m (0.035 inches) relative to the initial inner diameter of the shaft 11, provided the desired results with a minimum amount of expansion energy required relative to the high level of breakaway torque obtained for the assembled cam elements.

However, in some cases greater tri-lobe eccentricities may be desirable as, for example, when wide journal or cam elements are used and more volume for displacement of the expanded shaft material is required to avoid excessive longitudinal carryover of the displaced material. Tri-lobe openings with from 0.000127 m - 0.000508 m (0.005 to 0.020 inch) eccentricity have been tested but other dimensions could also be used as desired.

6) After expansion of the shaft, the end loading of the shaft is released by backing-off the force-applying means. The assembled camshaft is then removed from the fixture for other finishing steps, if any, which may be required, such as hardening of the cams if they are not pre-hardened, or grinding of the cams and journals.

The force of the end-loading of the shaft by the back-up bushing 46 acting in opposition to the stop block 32 should be sufficient to prevent significant longitudinal growth of the shaft 11 during "ballizing". This causes all the growth to be radial and provides the preferred complete filling of the tri-lobe openings and the further expansion of the shaft material radially beyond the openings 15 in the spaces located longitudinally between the elements 12 and 14. In addition, the end-loading prevents the elements from being locked against the spacers by lengthwise growth of the shaft during "ballizing" and, thus, after release of the end-loading, allows easy removal of the assembled camshaft 10 from the fixture 27. Bending and other damage which might otherwise result from forced removal are thereby avoided.

Advantages

From the foregoing description of certain preferred embodiments of an improved camshaft assembly, assembly apparatus and assembly methods, it is seen that the various features of the invention provide numerous advantages including:

more accurate axial location of cam, journal and other elements on the shaft;

higher breakaway torques with minimal thrust energy for forcing the ball through the tubular shaft by reason of improved splined tri-lobe or other curved polygon-shaped openings, improved shaft material selection, and end-loading the shaft to prevent axial growth;

ease of removal from the fixture through prevention of axial growth of the shaft;

better angular indexing by adjustable locators and locating plungers; and

loaded fixture inspection with flush pin gauges carried on the locating plungers.

A camshaft assembly as described in Figures 1 to 5 of this application is disclosed and claimed in our co-pending European patent application No.88301147.0.

Claims

1. A method of manufacturing a camshaft assembly (10) for an internal combustion engine, said method including the steps of: providing a plurality of cam and journal elements (12,14), said elements

each including an axial opening (15), securing said elements (12,14) in predetermined fixed orientation and spacing with said openings (15) all aligned on a common axis, inserting an essentially straight hollow tubular shaft (11) having opposite ends (43,44) into said elements (12,14) in close-fitting relationship with said openings (15), longitudinally restraining one end (43) of the tubular shaft (11) whilst providing diametral clearance around portions adjacent said elements (12,14), and expanding the hollow tubular shaft (11) into mechanical interference engagement with all the element openings (15) and diametrically outwards thereof adjacent the elements (12,14) to secure the elements (12,14) permanently on to the shaft (11) in said predetermined orientation and spacing whilst forming within the tubular shaft (11) a uniform smooth-sided interior configuration (54), by forcing through the tubular shaft (11) an expander element (48) sufficiently larger than the inner diameter of the tubular shaft (11) to outwardly deform the wall of the tubular shaft (11) to the required extent, characterised in that the other end (44) of the tubular shaft (11) is longitudinally loaded to prevent elongation thereof during deformation of the tubular shaft (11) by said expander element (48).

2. A method according to claim 1, in which each of said axial openings is a non-round axial opening (15) having an odd number of regularly spaced lobes (16), said odd number being at least three, the periphery (20) of said opening (15) being primarily defined by joined outwardly-convex arcs (22,23) of varying radii, and having an eccentricity of from 0.4 to 1.5 percent of the uniform diameter (26) of the opening (15).

3. A method according to claim 2, in which said openings (15) are tri-lobed openings formed with a substantially constant uniform diameter dimension at all angular positions.

4. A method according to claim 3, in which each of the lobes (16) of the tri-lobed openings (15) includes at the end thereof at least one longitudinal serration (17) of radial extent approximately equal to the eccentricity of the tri-lobed opening, said tubular shaft (11) being expanded into intimate contact with said at least one serration (17).

5. A method according to claim 1, in which the expander element comprises a ball (48) having an outer diameter which is greater than the initial diameter of the tubular shaft (11) by an amount greater than the sum of (1) the eccentricity of the cam element opening (15) and (2) the initial diametral clearance between the tubular shaft (11), prior to the expansion thereof, and the least radial dimension of the cam element opening (15), but which is less than three times that sum.

6. Apparatus for assembling a multi-piece camshaft (10) by a method according to claim 1, in which said apparatus (27) comprises: locating means (30) for holding a plurality of hollow cam and journal elements (12,14) in predetermined fixed orientation and spacing relationship with one another, with central openings (15) in said elements (12,14) being aligned on a common axis, and means (48,50) for expanding the shaft (11) into mechanical interference engagment with all of the element openings (15) to secure the elements (12,14) permanently on to the shaft (11) in said predetermined orientation and spacing, characterised in that the apparatus includes a stop (32) for axially locating one end (43) of a hollow shaft (11) extending through the aligned openings (15) of said elements (12,14), and force-applying means (47;52) engageable with an opposite end (44) of the hollow shaft (11) and operable to load the shaft (11) against the stop (32) with a force adequate to prevent substantial axial growth of the shaft (11) during subsequent expansion.

7. Apparatus according to claim 6, in which said locating means comprise locators (30) recessed to receive and support the elements (12,14) in desired lateral and angular orientations relative to one another, and spacers (31) between the locators (30) to longitudinally separate and locate the elements (12,14) relative to one another, the locators (30) for the cam elements (12) further including adjustable locator blocks (38) in the recesses thereof which are engageable with the cam lobes to accurately adjust the desired angular location of the cam elements (12).

8. Apparatus according to claim 7, in which said locating means further include biasing devices (39) engageable with the cam elements (12) to urge said cam elements (12) against the respective adjustable locator blocks (38).

9. Apparatus according to claim 8, in which the biasing devices comprise resiliently-urged guide pins (39) and said pins incorporate ends (40) having stepped surfaces (42) co-operating with adjacent surfaces of the apparatus (27) to act as flush pin gauges indicating the condition of respective cam elements (12) loaded into the apparatus (27).

10. Apparatus according to claim 6, in which the force-applying means includes a hydraulic actuator (51,52) for transmitting the applied force.

11. Apparatus according to claim 10, in which the force-applying means further includes a hardened hollow bushing (46) engageable with said opposite end (44) of the shaft (11), which bushing is carried in a movable back-up block (34) for transmitting to the shaft (11) forces applied by the hydraulic actuator (51,52).

12. Apparatus according to claim 6, in which the force-applying means includes a mechanical actuator (47) for transmitting the applied force.

13. Apparatus according to claim 12, in which

the force-applying means comprises a screw actuator (47).

14. Apparatus according to claim 13, in which the force-applying means further includes a hardened hollow bushing (46) engageable with said opposite end (44) of the shaft (11), which bushing is carried in a movable back-up block (34) for transmitting to the shaft (11) forces applied by the screw actuator (47).

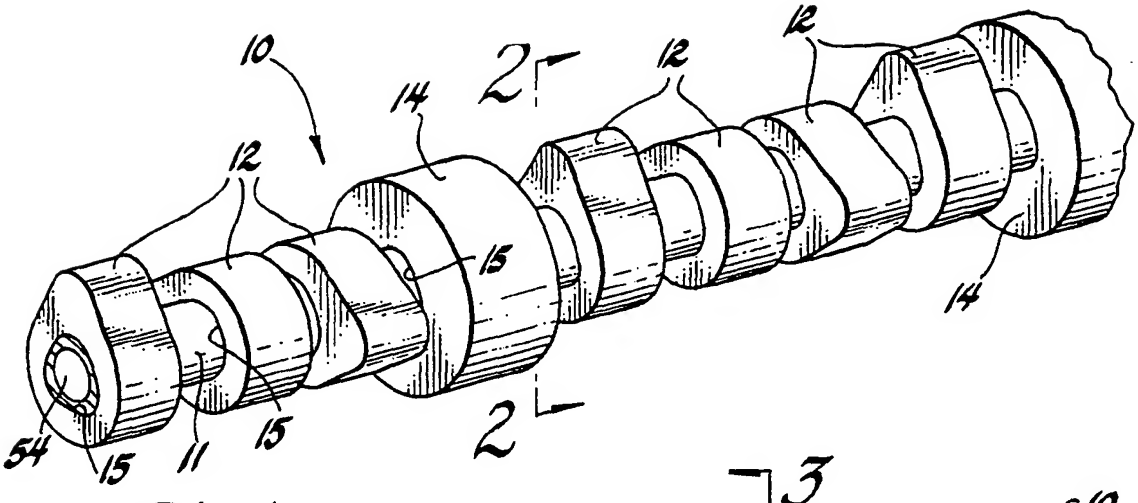

Fig. 1

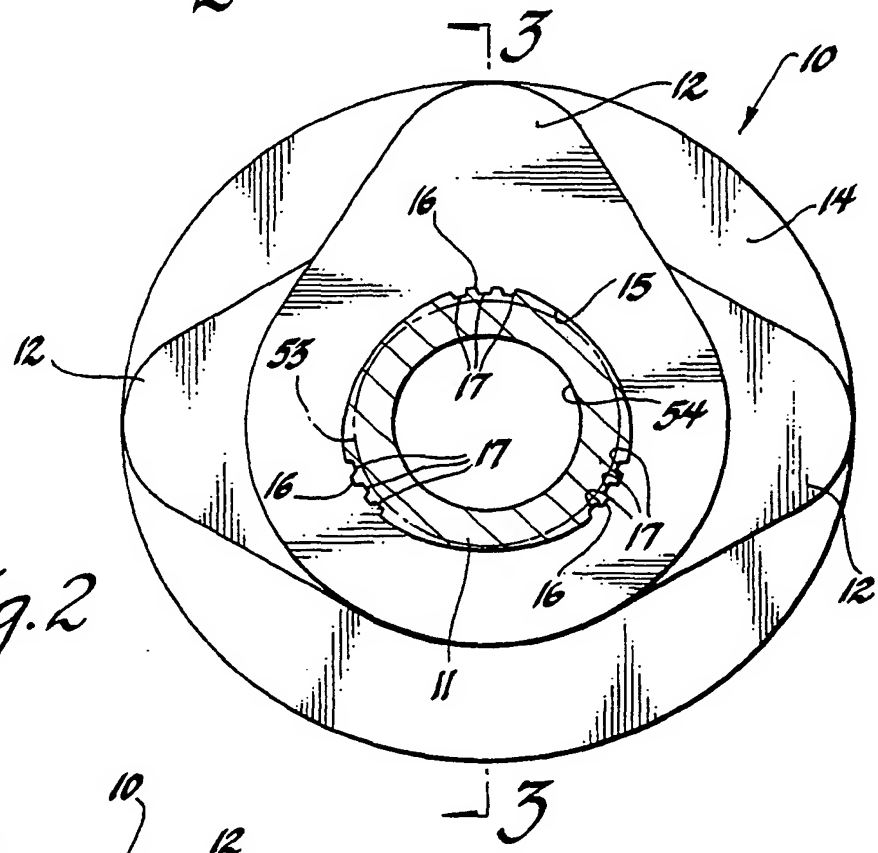

Fig. 2

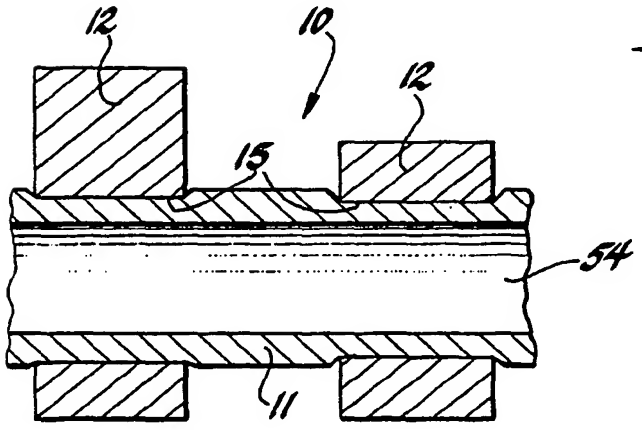

Fig. 3

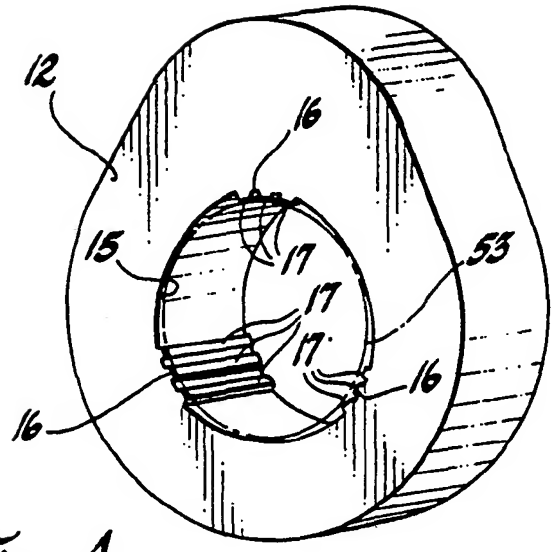

Fig. 4

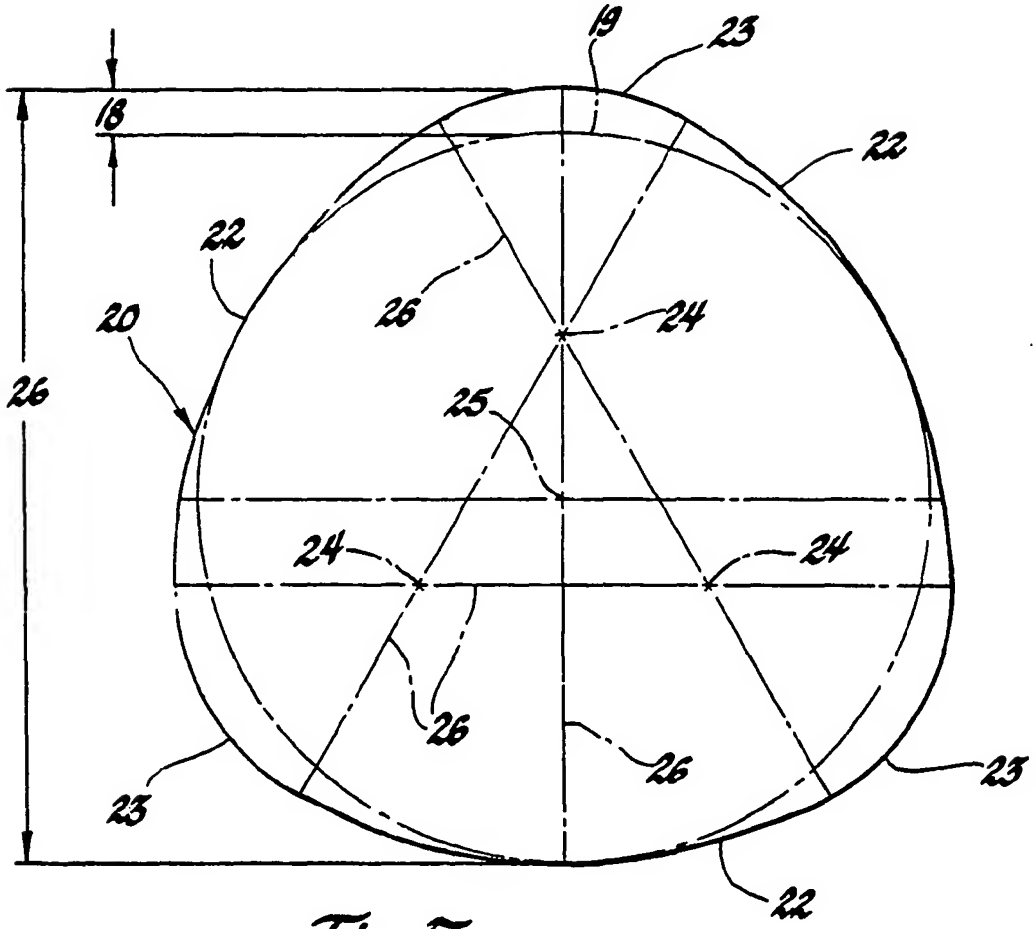

Fig. 5

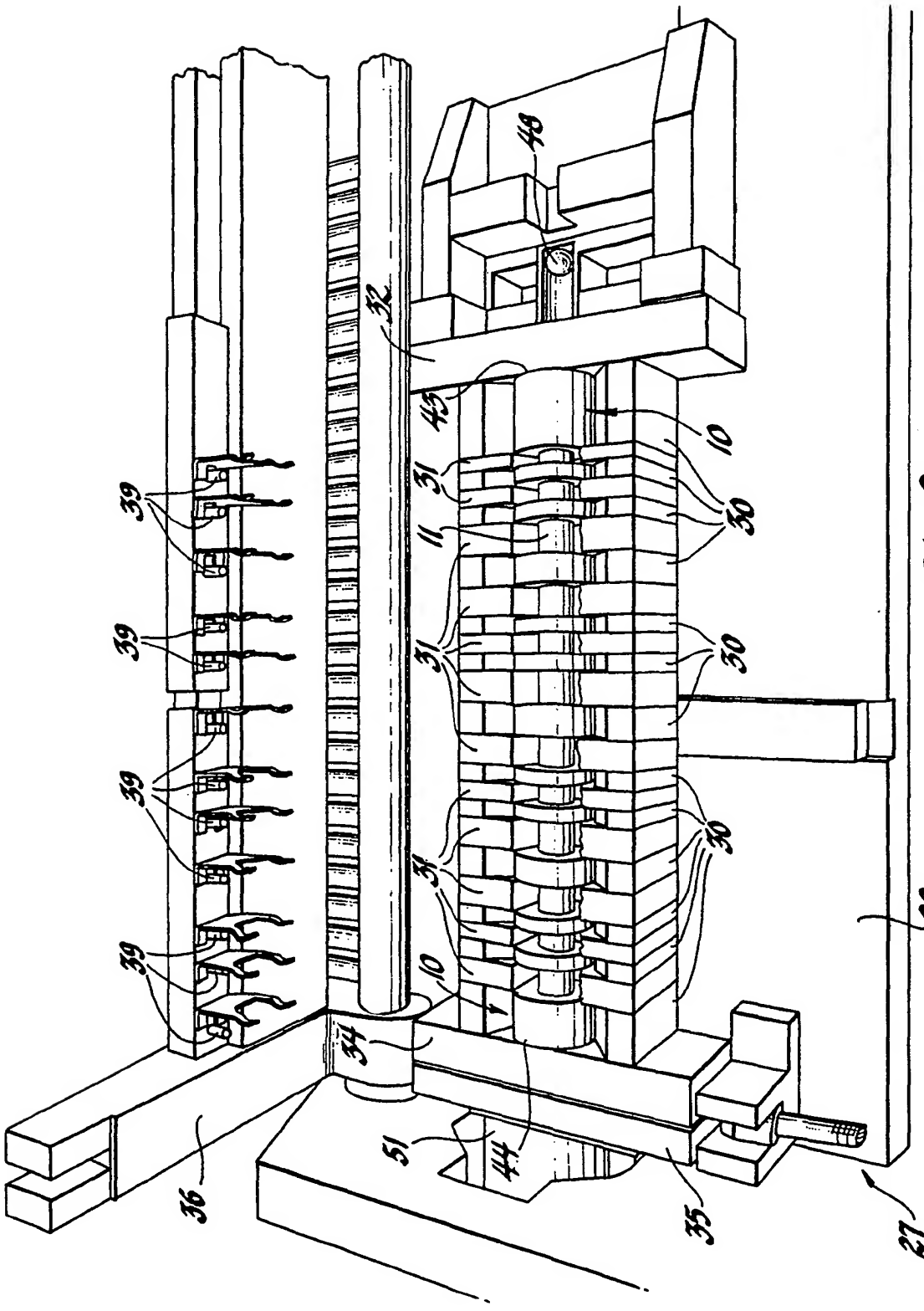

Fig. 6

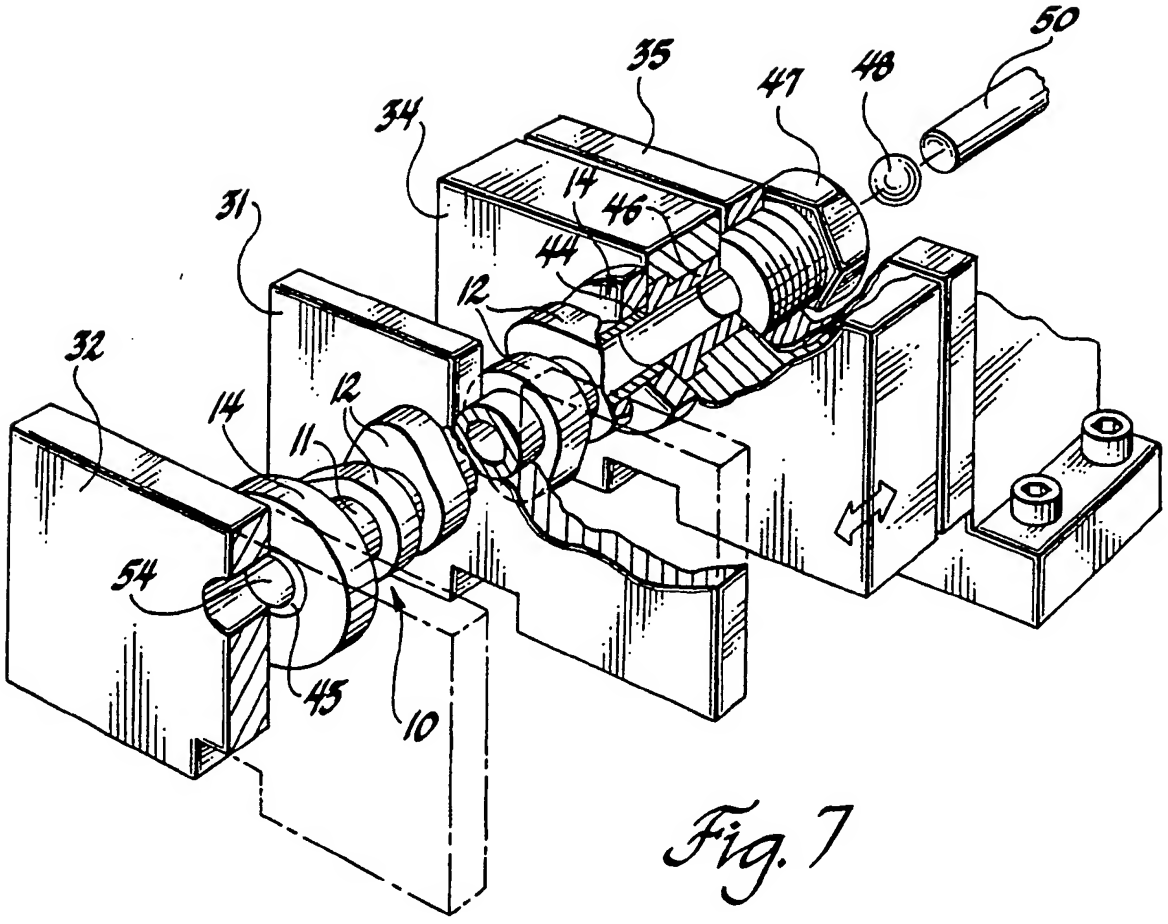

Fig. 7

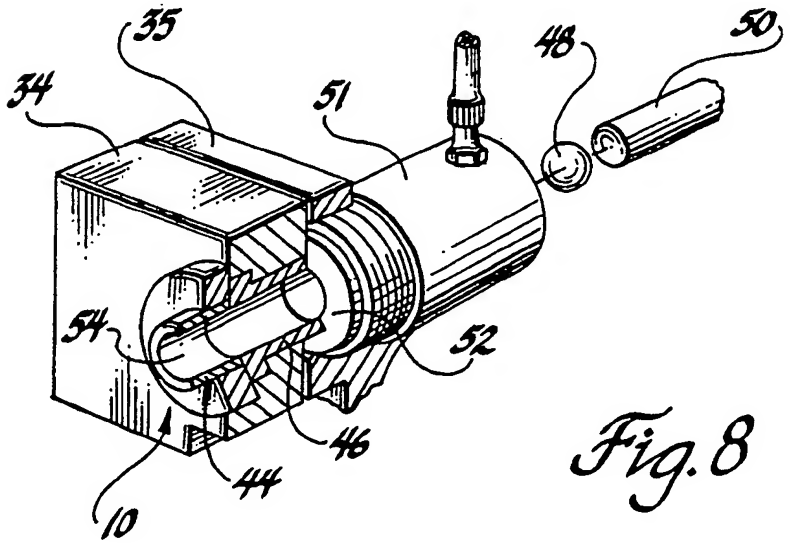

Fig. 8

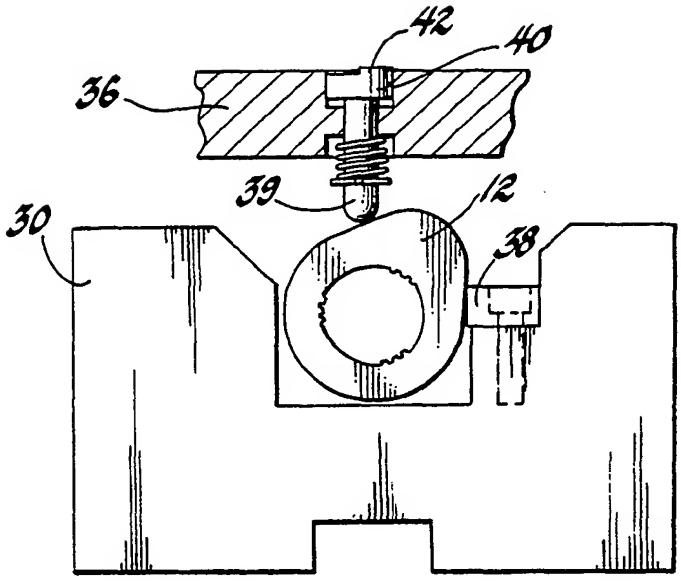

Fig. 9

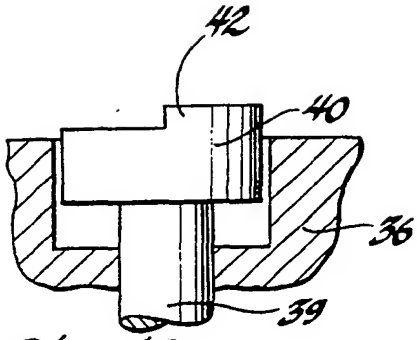

Fig. 10a

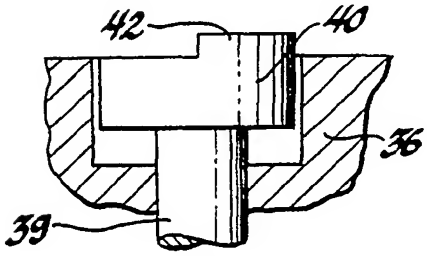

Fig. 10b

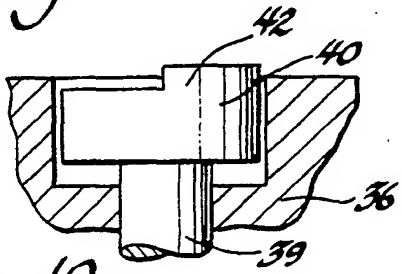

Fig. 10c

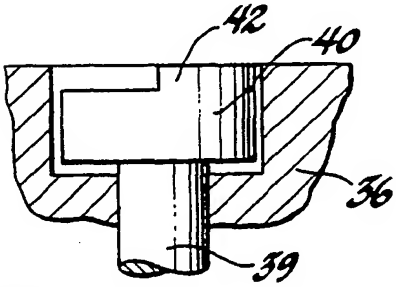

Fig. 10d

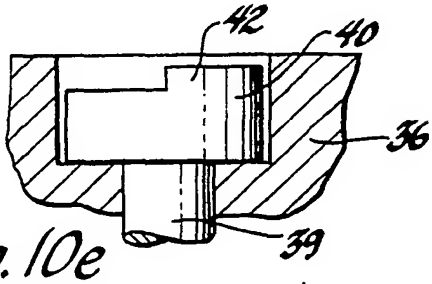

Fig. 10e

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(54) Method and apparatus for assembling camshafts.

(57) Camshaft assemblies, methods and apparatus are provided for making camshafts (10) by the expansion of tubular shafts (11) into pre-located cams (12), journals (14) and other elements, if desired. Features of the camshafts (10) include tri-lobe or poly-lobe element openings (15), preferably splined or serrated for low-energy filling and high torque-capacity, and high-strength low-alloy mild steel tubular shaft material. The method emphasizes loading the shaft (11) to prevent axial lengthening thereof during expansion thereof by a technique such as mechanical "ballizing". The apparatus (27) includes adjustable thrust blocks (38) and locating plungers (39) with incorporated flush pin gauges (40,42) together with hydraulic or other loading means (51), all for use in carrying out the assembly method with various benefits from the incorporated features.

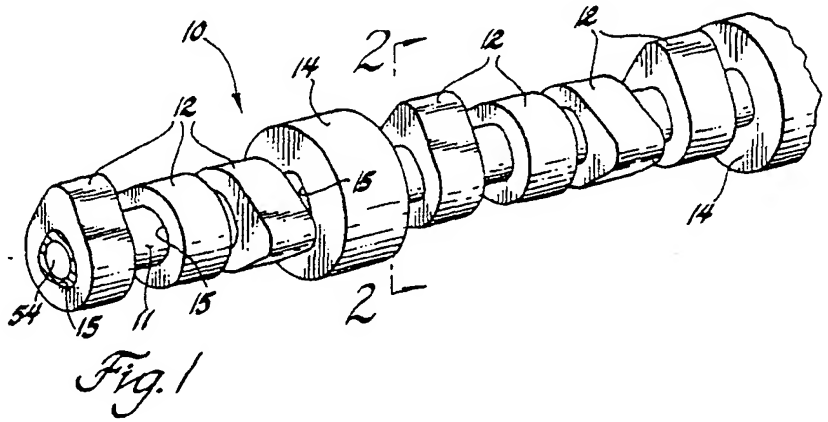

Fig. 1

EP 0 389 070 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 20 1407

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	GB-A-2 050 207 (MANNESMANN) * page 1. line 116 - page 2. line 13; figures 1-10 *	1,2,5,6,7	F 01 L 1:04
D,A	US-A-4 597 365 (MADAFFER) * column 2, line 50 - column 3, line 43; figures 1-7 *	1,5,6	
P,A	EP-A-0 230 731 (HUGHES) * column 3, line 31 - column 4, line 25 * * column 5, lines 1 - 22 @ column 6, lines 21 - 35 @ column 7, lines 19 -47; figures 1-5 *	1,6,7	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

F 01 L
F 16 H

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	23 January 91	LEFEBVRE L.J.F.

CATEGORY OF CITED DOCUMENTS

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